Apparatus for Generating and Conducting a Fluid Flow, and Method of Monitoring Said Apparatus

5   FIELD OF THE INVENTION

This invention relates to an apparatus for generating and
conducting a fluid flow comprising a displacement pump and
a measuring arrangement, and to a method of monitoring said
10   apparatus.

BACKGROUND OF THE INVENTION

15   Displacement pumps, as is well known, are pumps which
generate a discontinuous fluid flow, particularly a pulsing
fluid flow, in the lumen of a flow vessel deformable at
least in sections, particularly elastically, such as a
flexible tube. For example, U.S. Patents 4,909,710,
20   5,165,873, 5,173,038, 5,263,830, 5,340,290, 5,683,233,
5,701,646, 5,871,341, and 5,888,052 as well as
WO-A 97/41353, WO-A 98/22713 and WO-A 98/31935 each
disclose an apparatus for generating and conducting a
discontinuous fluid flow which comprises a displacement
25   pump with at least one flow vessel of deformable lumen,
which serves to conduct the fluid flow, and with a pump
drive for deforming the lumen of the flow vessel.

During operation of the displacement pump, the pump drive
acts on sections of the fluid-conducting flow vessel such
that displacement motions are imparted to the flow vessel
which temporarily deform the lumen of the flow vessel,
5   particularly in an oscillating manner, thus transferring
the fluid in the desired direction of flow. In each of the
displacement pumps disclosed in U.S. Patents 4,909,710,
5,173,038, 5,340,290, 5,701,646, and 5,871,341 and in
WO-A 97/41353, peristaltic displacement motions are
10   produced by a non-circular-cylindrical surface of a pump
drive rotating about an axle, which surface rests against
the flow vessel, while in U.S. Patents 5,165,873,
5,263,830, 5,683,233, and 5,888,052 as well as in
WO-A 98/31935, the displacement motions are caused by
15   linear motions that a pump drive comprising pumping fingers
performs against the flow vessel.

The drive motor for the pump drive is usually an electric
motor coupled directly to the pump drive by a drive shaft.
20   The drive motor and the pump drive may also be coupled
together by a toothed gearing or a belt drive. Furthermore,
an eccentric or cam disk or a crank mechanism, for example,
may be used to provide mechanical coupling between the
electric motor and the pump drive, see WO-A 98/22713 and
25   U.S. Patents 5,165,873, 5,263,830, 5,683,233, and
5,888,052. Instead of an electric motor, a piston-type air
motor or a hydraulic motor can be used as the drive motor
for producing linear finger motions, as is disclosed in
WO-A 98/31935, for example.

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Displacement pumps of the kind described, because of a
substantially homogeneous, smooth internal wall of the flow

vessel and because of the absence of drive elements
rotating in the fluid flow, are particularly suited for
applications in which stringent chemical and/or biological
purity requirements are placed on the fluid-conducting
5   lumen of the flow vessel. Therefore, displacement pumps are
frequently used in samplers for chemobiological analyses,
particularly in drinking water and sewage treatment plants.
Such samplers with a displacement pump are shown in U.S.
Patents 5,587,926 and 5,701,646, for example.
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A physical parameter that is important for the operation of
such samplers, particularly for metering liquid samples, is
the actual volume of liquid delivered or metered. To
determine this volume, the instantaneous volume flow rate
15   of the liquid is determined as a measure of the volume of
liquid delivered per unit time, and integrated over a
delivery time.

During steady-state operation of the displacement pump, the
20   volume flow rate is strongly dependent on the rate of the
displacement motions. This relationship is virtually linear
over a wide operating range of the pump, i.e., the volume
flow rate is proportional to the rate of the displacement
motions, and thus to a set oscillation frequency of the
25   lumen. Therefore, particularly during steady-state
operation of the displacement pump, the calculation of the
volume of fluid delivered is frequently based on an average
volume flow rate for a set displacement motion.

30   The displacement motions of the flow vessel, and thus the
oscillations of the lumen of the vessel, are commonly
determined indirectly. To accomplish this, a drive motion

of the drive motor is sensed, for example at the motor's
drive shaft, using electrodynamic or optical revolution
counters, and mapped into a drive signal representative of
this drive motion. In suitable evaluation electronics, the
5   drive signal is converted into the volume flow rate and/or
into measurement signals representative of the volume of
fluid delivered.

However, the drive motions, and thus the measurement
10   signals derived therefrom, are representative of the volume
flow rate only if, on the one hand, the flow vessel is
filled with liquid in a known manner, particularly
completely, and if, on the other hand, no slip occurs
between the pump drive and the drive motor. Slip may easily
15   occur in the case of a belt drive or in the case of a pump
drive that is merely press-fitted to the drive shaft.

This degree of filling of the flow vessel is strongly
dependent on the mounting position of the flow vessel,
20   particularly on the instantaneous suction head. This can be
determined a priori, e.g., during start-up, and stored as a
setting value in the evaluation electronics, but in the
case of samplers, particularly in the case of mobile
samplers, the mounting position is variable, i.e., it must
25   be determined anew for each application and, if necessary,
stored. Furthermore, the mounting position, particularly
also in the case of stationary samplers, may vary because
the liquid level at a liquid-sampling location is subject
to more or less wide variations.

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It has also turned out that, when viewed over the entire
operating time, material properties of the flow vessel,

such as its tightness, its elasticity, or a property of the
inside wall, may also be subject to permanent changes. For
instance, deposits on the inside wall may lead to necking
or clogging of the flow vessel, and must be detected in
5   time or precluded. Also, damage to the flow vessel, such as
leaks, may result in the apparatus becoming useless.

To monitor a displacement pump, particularly a current
operational status of the pump drive and/or the flow
10 vessel, additional measures are therefore necessary which
detect one or more of the aforementioned parameters during
operation and which compensate for the effect of these
parameters on the calculated volume flow rate.

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SUMMARY OF THE INVENTION

It is therefore an object of the invention to provide an
apparatus comprising a displacement pump and a measuring
20 arrangement which robustly and reliably senses an actual
displacement motion of the flow vessel and which delivers a
measurement signal representative of this motion that is
particularly suited for generating a flow rate estimate
representative of the instantaneous volume flow rate and/or
25 for generating a status signal signaling a current
operational status.

Another object of the invention is to provide a method
which supplies information serving to monitor such an
30 apparatus.

To attain the first-mentioned object, a first variant of
the invention provides an apparatus for generating a fluid
flow, said apparatus comprising:
- a displacement pump
5   -- with at least one flow vessel of deformable lumen, which
        serves to conduct a fluid,
    -- with a pump drive for producing displacement motions of
        the flow vessel which deform the lumen and cause the
        fluid flow, and
10 -- with a support means for holding the flow vessel; and
    - a measuring arrangement responsive to the displacement
        motions performed by the flow vessel,
    -- with a pressure sensor for sensing a static pressure in
        the fluid and providing a sensor signal representative
15   of the displacement motions, and
    -- with evaluation electronics for the sensor signal.

A second variant of the invention provides an apparatus for
generating a fluid flow, said apparatus comprising:
20 - a displacement pump
    -- with at least one flow vessel of deformable lumen, which
        serves to conduct a fluid,
    -- with a pump drive for producing displacement motions of
        the flow vessel which deform the lumen and cause the
25   fluid flow, and
    -- with a support means for holding the flow vessel,
    --- the flow vessel being compressed by the pump drive in
        operation temporarily and in sections and forced
        against the support means such that the support means
30   is elastically strained; and
    - a measuring arrangement responsive to the displacement
        motions performed by the flow vessel,

-- with a strain sensor for sensing a strain of the support
   means and providing a sensor signal representative of
   the displacement motions performed by the flow vessel,
   and

5   -- with evaluation electronics for the sensor signal.

Furthermore, the invention provides a method of monitoring
an apparatus serving to generate a fluid flow and
comprising:

10   - a displacement pump
     -- with at least one flow vessel of deformable lumen, which
        serves to conduct a fluid,
     -- with a pump drive for producing displacement motions of
        the flow vessel which deform the lumen and cause the
15   fluid flow,
     -- with a drive motor for the pump drive, and
     -- with a support means for holding the flow vessel; and
     - a measuring arrangement responsive to the displacement
       motions of the flow vessel and comprising a pressure
20   sensor for sensing a static pressure in the fluid,
     said method comprising the steps of:
     - causing drive motions of the drive motor for producing
       the displacement motions of the flow vessel;
     - sensing the first pressure with the pressure sensor for
25   generating a sensor signal representative of the
       displacement motions; and
     - deriving from the sensor signal a status signal signaling
       a current operational status of the apparatus.

30   Furthermore, the invention consists in the use of an
     apparatus according to the invention in a sampler,
     especially in a mobile sampler or a portable sampler.

In a first preferred embodiment of the first or second
variant of the invention, the evaluation electronics derive
from the sensor signal a flow rate estimate representative
5   of an instantaneous volume flow rate of the fluid.

In a second preferred embodiment of the first or second
variant of the invention, the evaluation electronics derive
from the sensor signal a first measurement signal
10   representative of a frequency of the displacement motions.

In a third preferred embodiment of the first or second
variant of the invention, the evaluation electronics derive
from the sensor signal a volume estimate representative of
15   a totalized volume of fluid delivered.

In a fourth preferred embodiment of the first or second
variant of the invention, the evaluation electronics derive
from the sensor signal a status signal representative of a
20   current operational status of the displacement pump.

In a fifth preferred embodiment of the first or second
variant of the invention the pump drive is a rotary pump
drive.
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In a sixth preferred embodiment of the first or second
variant of the invention the pump drive is a linear pump
drive.

30   In a seventh preferred embodiment of the first variant of
the invention, the evaluation electronics derive from the

sensor signal a second measurement signal representative of
a suction head of the apparatus.

A basic idea of the invention is to determine the
5   displacement motion of the flow vessel, or the oscillations
of its lumen, not on the basis of their causes, namely the
drive motions of the drive motor, but on the basis of their
effects in the apparatus. The reactions of the apparatus to
the displacement motions, which reactions have to be
10   sensed, are, for example, a varying pressure in the fluid
flow and/or a partial deformation, particularly an elastic
deformation, of the support means of the displacement pump.

One advantage of the invention is that the volume flow rate
15   can be determined independently of the mechanical coupling
provided between the drive motor and the pump drive and on
the basis of a single sensor signal.

Another advantage of the invention is that the measuring
20   arrangement, and thus the method, can be used both in
apparatus with electric-motor-driven displacement pumps and
in apparatus with hydraulically or pneumatically operated
displacement pumps.

25   A further advantage of the invention is that existing
apparatus or samplers of the kind described can be readily
retrofitted with such a measuring arrangement.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention and further advantages will become more
apparatus from the following description of embodiments
5   taken in conjunction with the accompanying drawings, in
which like reference characters represent like parts
throughout the various figures. Reference characters that
have already been assigned are not shown in subsequent
figures if this contributes to clarity. In the drawings:
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Fig. 1   shows schematically the use of an apparatus for
            transferring a fluid in a sampler;

Fig. 2   is a front view of an embodiment of a
15   displacement pump of the apparatus of Fig. 1;

Fig. 3   is a part section taken along line I-I of Fig. 2;

Fig. 4   shows schematically a first effect of the
20   displacement pump of Fig. 2 as well as a
            measuring arrangement responsive to this first
            effect;

Fig. 5,   a section of the side of view of Fig. 3, shows
25   schematically a second effect of the displacement
            pump as well as a measuring arrangement
            responsive to this second effect;

Fig. 6   is a schematic block diagram of an embodiment of
30   the evaluation electronics of the measuring
            arrangement of Fig. 4 and/or Fig. 5;

Fig. 7   is a schematic block diagram of an embodiment of
            the evaluation electronics of the measuring
            arrangement of Fig. 1; and

5   Fig. 8   shows waveforms of signals generated with the
            measuring arrangement.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

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While the invention is susceptible to various modifications
and alternative forms, exemplary embodiments thereof have
been shown by way of example in the drawings and will
herein be described in detail. It should be understood,
15 however, that there is no intent to limit the invention to
the the particular forms diclosed, but on the contrary, the
intention is to cover all modifications, equivalents, and
alternatives falling within the spirit and scope of the
invention as defined by the intended claims.

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Fig. 1 shows an apparatus for transferring a fluid,
particularly liquid, using a displacement pump 1. The
apparatus is especially suited for use in samplers PN for
taking samples of liquids, e.g., drinking water or sewage
25 water, and, if necessary, for storing such samples.

In one embodiment of the invention, shown in Figs. 2 and 3,
displacement pump 1 comprises a support means 11 designed
as a pump casing, a pump drive 12 held by support means 11,
30 particularly a drive designed as a displacing member, and a
flow vessel 13 of variable lumen 13A, particularly of a
cross section variable at least in sections, for conducting

the fluid. For flow vessel 13, all elastic tubes commonly used in such displacement pumps, e.g., tubes made of polyethylene or silicone, can be employed. Flow vessel 13 may be of one-part or multipart construction.

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During operation of the apparatus, a displacement motion s_{13}, particularly a peristaltic motion, of predeterminable frequency, e.g., a frequency in a range of 10 Hz to 20 Hz, is imparted by pump drive 12 to flow vessel 13 such that

10   the fluid in the oscillating lumen 13A of flow vessel 13 flows in a predetermined direction, particularly in a pulsing manner. In the apparatus of the embodiment, the displacement motion is a wave motion of the wall of flow vessel 13, and thus of the lumen 13A enclosed by this wall,

15   with the wave velocity determining the volume flow rate, see Fig. 4.

To produce the displacement motion s_{13}, pump drive 12, as shown schematically in Fig. 4, acts on flow vessel 13 with

20   a time-variable and locally variable compression force F, particularly a periodically variable force, such that within an effective compression range, flow vessel 13, and thus its lumen 13A, is deformed, particularly elastically, thus displacing the fluid. In the displacement pump 1 of

25   the embodiment shown in Figs. 2 and 3, this is accomplished by causing the pump drive 12 of noncircular cross section to roll on flow vessel 13, thereby periodically compressing the flow vessel 13 against support means 11 and allowing it to relax. To that end, as shown in Fig. 2, sections of pump

30   drive 12 rest against flow vessel 13, which is also held by support means 11.

In the embodiment, pump drive 12 is designed as a drum- or
disk-shaped displacing member of noncircular cross section,
i.e., a displacing member with a non-circular-cylindrical
surface. To that end, the displacing member has four
5   spaced-apart roller elements, particularly rotatably
mounted elements, which during operation of displacement
pump 1 act sequentially on flow vessel 13 according to a
set direction of rotation of pump drive 12. Pump drive 12
can also be implemented with all other displacing members
10   of noncircular cross section that are commonly used in such
pumps, or with a rotary pump drive provided with
eccentrically mounted roller elements, see U.S. Patents
5,173,038, 5,683,233, 5,701,646, and 5,871,341 as well as
WO-A 97/41353, the disclosers of which are hereby
15   incorporated by reference. In place of rotary pump drives,
linear pump drives implemented with, e.g., pumping fingers
or helical displacing members can be used, see U.S. Patents
4,909,710, 5,165,873, 5,888,052, and 5,263,830, the
disclosers of which are hereby incorporated by reference.
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Pump drive 12, as is usual with displacement pumps with a
rotary pump drive, is mechanically coupled, e.g., by a
gearing or a driving belt, to a drive shaft 15 of a drive
motor 14, particulary an electric motor; it may also be
25   slipped directly over drive shaft 15. In operation, drive
motor 14 performs drive motions at a predetermined rate,
here rotary motions at a preferably adjustable motor speed
proportional to the frequency of the displacement motions
s_{13}, e.g., at a speed of 200 min^{-1} to 3000 min^{-1}, which,
30   after being geared down if necessary, are transmitted via
drive shaft 15 to pump drive 12. If pump drive 12 is a
linear drive, it may also be driven by a hydraulic motor or

an air motor, see WO-A 98/31935, the disclosers of which
are hereby incorporated by reference.

To draw liquid during operation of the apparatus, flow
5   vessel 13 communicates at an inlet end with a liquid-
sampling location. As shown schematically in Fig. 1, liquid
can be sampled by immersing flow vessel 13 in the liquid,
which is conducted in an open channel or contained in a
basin, and drawing the liquid in against the force of
10 gravity as the lumen 13A oscillates in the manner described
above; the liquid may also be allowed to flow in from a
suitable liquid-sampling location in the direction of
gravity and/or from a pipe.

15 The apparatus further comprises a measuring arrangement 2
which responds to the displacement motions s_{13} performed by
flow vessel 13. Measuring arrangement 2 comprises
evaluation electronics 22, which are supplied with a sensor
signal x_{21} representative of the displacement motions s_{13}.
20

To generate sensor signals x_{21}, measuring arrangement 2,
according to a first variant of the invention, comprises a
preferably capacitive or resistive pressure-sensor 21',
which is in contact with the fluid and which, as shown
25 schematically in Fig. 4, responds to an instantaneous first
pressure p_1, particularly a static pressure, that exists in
the fluid in lumen 13A. For this purpose, pressure sensor
21' has at least one pressure-measuring chamber that is
isolated from lumen 13A by at least one pressure diaphragm
30 and on which the pressure p_1 acts in operation via this at
least one pressure diaphragm.

The pressure to be sensed, p_1, is an instantaneous internal
pressure that is adjusted by means of displacement pump 1
in an inlet-side region of flow vessel 13, and that
exhibits a calibratable dependence on a current operational
5   status of the apparatus, e.g., on the mounting position
and/or the filling of the flow vessel and/or the
instantaneous frequency of the displacement motions s_{13}.
During operation of displacement pump 1, pressure p_1 is set
at least temporarily, particularly also with flow vessel 13
10   not filled with liquid, at a value in the range of 200 hPa
to 400 hPa (= 0.2 bar to 0.4 bar), and thus at a value
lower than a static second pressure p_2, which acts on flow
vessel 13 from outside. Pressure p_2 may, for instance, be
an atmospheric pressure of about 1000 hPa.
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In this variant of the invention, measuring arrangement 2
serves in particular to sense pressure p_1 and map it into
sensor signal x_{21} even if pressure p_1 is set at a value
lower than that of pressure p_2. To accomplish this,
20   pressure sensor 21' may be designed either as an absolute
pressure sensor with an evacuated pressure-measuring
chamber or as a relative pressure sensor that senses
pressure p_1 relative to pressure p_2. To mount pressure
sensor 21', a portion of flow vessel 13 is preferably
25   designed as an adapter, as shown schematically in Fig. 4.

According to a second variant of the invention, measuring
arrangement 2 comprises a piezoresistive strain sensor
21'', particularly a strain sensor mounted directly on
30   support means 11, which, as shown schematically in Fig. 5,
senses strain in support means 11 caused by displacement
motions s_{13} of flow vessel 13, and which converts this

strain into sensor signal x_{21}. Strain sensor 21'' may also
be a displacement, velocity, or acceleration sensor for
sensing relative or absolute strain.

5   Because of the compression of flow vessel 13 against
support means 11, the compressive force F of pump drive 12
acting on flow vessel 13 is partially converted to a
compression spring force acting on support means 11,
whereby support means 11 is also deformed in sections,
10   particularly elastically. This is represented in Fig. 5 by
the dotted lines. Through this deformation, support means
11 is subjected to a measurable strain whose extent is
determined in particular by the instantaneous pressure p_1
in lumen 13A of flow vessel 13. The compression spring
15   force, and thus the strain in support means 11, is also
dependent on the material, particularly on its modulus of
elasticity, and/or on an instanteous three-dimensional
shape of flow vessel 13, for example.

20   This dependence of the deformation of support means 11 can
be accurately determined by suitable calibration
measurements, in which flow vessel 13 is successively
filled with liquids and left empty in a defined manner,
with a corresponding instantaneous value of sensor signal
25   x_{21} being stored as a reference value for the instantaneous
filling in evaluation electronics 22.

The sensor signal x_{21} generated by pressure sensor 21'
according to the first variant of the invention can
30   advantageously be used to determine a flow rate estimate
X_v, which is representative of the instantanous volume flow

rate, and/or a volume estimate, which is representative of
the volume flow rate integrated over a delivery time.

In a preferred embodiment of the first variant of the
5   invention, evaluation electronics 22, as shown in Fig. 6,
comprise a bandpass circuit 220 of adjustable bandwidth,
which transmits a component of sensor signal x_{21},
particularly a component with the frequency of
displacement motion s_{13}, and a frequency counter 221
10   connected to the output of bandpass circuit 220. Bandpass
circuit 220 may, for instance, be implemented with a
switched-capacitor filter and/or a voltage-controlled
active filter as is familiar to those skilled in the art.

15   Bandpass circuit 220 and frequency counter 221 convert
sensor signal x_{21} to a first measurement signal x_{221},
particularly a digital signal, with an instantaneous value
X_ω of measurement signal x_{221} representing the frequency of
displacement motions s_{13}.
20

Bandpass circuit 220 serves in particular to remove DC
components of sensor signal x_{21} and reject higher-frequency
interference voltages. Accordingly, the bandwidth of
bandpass circuit 220 is so adjusted that any changes in the
25   frequency of displacement motion s_{13}, for example changes
due load-induced variations in motor speed, will not result
in sensor signal x_{21} being blocked. If this frequency
varies in a wide range of, e.g., $\pm 5 \text{ s}^{-1}$, the bandwidth of
bandpass circuit 220, which is preferably configured as a
30   switched-capacitor filter, can also be tracked, for example
by means of an instantaneous motor speed setting generated
by evaluation electronics 22. The setting may be derived

from a drive signal picked off directly from the drive
motor in the above-mentioned manner.

For an apparatus of the kind described, the volume flow

5   rate of a liquid is dependent on the concrete realization
of displacement pump 1, namely on the design of pump drive
12 and flow vessel 13, and on the frequency of displacement
motions s_{13}.

10   Besides being determined by the respective nature of
displacement motion s_{13}, the instantaneous volume flow rate
is dependent on the suction head, which is determined by
the instantaneous spatial distance between the displacement
pump and a liquid level. In the case of a permanently

15   installed apparatus, e.g., if the apparatus is used in a
stationary sampler PN, and with a practically invariable
liquid level, this suction head must be determined at the
start-up of the apparatus and stored as a fixed value K_h in
evaluation electronics 22. Then, particularly with a liquid

20   flowing in the steady state, the following simple
proportionality, which is readily verifiable by suitable
calibration measurements, holds for the flow rate estimate
X_v:

25         $$X_v = K_1 \cdot K_h \cdot X_\omega \qquad\qquad\qquad (1)$$

where K_1 is a constant representing the dependence of the
volume flow rate on the frequency of the displacement
motion s_{13} and on the instantaneous suction head,

30   particularly a constant to be determined by calibration. If
necessary, the flow rate estimate X_v may also be
approximated by a higher-order polynomial, of course.

Thus, during steady-state operation of the apparatus, the
flow rate estimate X_v can advantageously be derived
directly from measurement signal x_{221}. In the case of the

5   displacement pump 1 of the embodiment shown in Fig. 2, the
volume flow rate is proportional to four times the
frequency of displacement motion s_{13}. To determine the
volume estimate, the flow rate estimate X_v must only be
integrated over the delivery time, for example by

10   multiplying this estimate X_v by the latter or by a number
of measured zero crossings of the bandpass-filtered sensor
signal provided at the output at bandpass circuit 220.

If the mounting position of the flow vessel 13 is variable,

15   e.g., if the apparatus is used in a mobile or portable
sampler PN, and/or with a varying liquid level, the
instantaneous suction head must be updated for a more
accurate determination of the flow rate estimate X_v.

20   Therefore, in a further preferred embodiment of the first
variant of the invention, a second measurement signal x_{222}
is derived from sensor signal x_{21}, with an instantaneous
value X_h of measurement signal x_{222} representing the
instantaneous suction head. In Eq. (1), therefore, only the

25   fixed value K_h has to be replaced by the value X_h of
measurement signal x_{222}, so that the flow rate estimate X_v
will now be given by

$$X_v = K_1 \cdot X_h \cdot X_\omega \qquad\qquad (2)$$

30

To generate measurement signal x_{222}, sensor signal x_{21} is
smoothed by a low-pass circuit 222 of evaluation

electronics 22, as shown in Fig. 6. Low-pass circuit 222
has a cutoff frequency much lower than the frequency of
displacement motion s_{13}, namely a cutoff frequency of,
e.g., 0.5 Hz to 2 Hz. Thus, of the sensor signal x_{21}, only
5   a component of zero frequency serving as measurement signal
x_{222}, e.g., an instantaneous mean value of sensor signal
x_{21}, is passed by low-pass circuit 222. A transmitted
instantaneous mean value of sensor signal x_{21} serves as a
measured value X_h representing the instantaneous suction
10   head. With increasing suction head, e.g., with decreasing
liquid level, the pressure p_1 sensed by sensor 21 would
drop and the sensor signal x_{21} would have a correspondingly
decreasing mean value; analogously, with decreasing suction
head, the mean value of sensor signal x_{21} would increase.
15

Furthermore, evaluation electronics 22 can serve to derive
from sensor signal x_{21} a third measurement signal x_{223},
which is representative of a degree to which flow vessel 13
is filled with liquid. To accomplish this, sensor signal
20   x_{21}, as shown in Fig. 6, is applied through bandpass
circuit 220 to a rectifier circuit 223 which provides at
its output the measurement signal x_{223} in the form of a DC
voltage, with an instantaneous value of measurement signal
x_{223} serving as an estimate of the instantaneous degree of
25   filling; if necessary, a corresponding direct current may,
of course, be used for the measurement signal x_{223}.
Rectifier circuit 223 can be implemented with a
conventional amplitude-measuring or rms-measuring AC-DC
converter, for example.
30

To implement Eqs. (1) and/or (2), evaluation electronics 22
further comprise a microcomputer 227, to which the

measurement signal x_{221} and/or the measurement signal x_{223} and, if necessary, the measurement signal x_{222} are applied through signal ports that convert the signals from analog to digital form; if necessary, frequency counter 221 and/or
5   rectifier circuit 223 may, of course, be implemented as digital circuits, which then receive a sensor signal that was digitized at the output of bandpass circuit 220.

Sensor signal x_{21}, generated by pressure sensor 21'
10   according to the first and/or second variants of the invention, can also be used in evaluation electronics 22 to derive a status signal Z, particularly a digital status signal, which signals a current operational status of displacement pump 1 and, hence, a current operational
15   status of the sampler PN comprising the apparatus.

Therefore, in a preferred embodiment of the first or second variant of the invention, evaluation electronics 22, as shown schematically in Fig. 7, comprise a first Schmitt
20   trigger 224, which converts the measurement signal x_{221} delivered by frequency counter 221 to a binary first monitoring signal x_{221}'. To that end, measurement signal x_{221} is compared with a frequency reference value of Schmitt trigger 224 which is set so that the monitoring signal x_{221}'
25   is at a high level when the frequency of displacement motion s_{13} is greater than or equal to a minimum frequency during steady-state operation of displacement pump 1. The frequency reference value must be determined and set during start-up, for which purpose the displacement pump 1 is, for
30   example, subjected to a maximum load to be expected during operation.

In another preferred embodiment of the first variant of the
invention, the mean value of sensor signal x_{21} being
transmitted by low-pass circuit 222 is applied to a second
Schmitt trigger 225 of evaluation electronics 22, as shown

5   in Fig. 7. At the output of Schmitt trigger 225, a binary
second monitoring signal x_{222}' is available. Monitoring
signal x_{222}' serves to signal whether or not the pressure p_1
is less than a pressure reference value set at Schmitt
trigger 225. Accordingly, the pressure reference value is

10   set so that monitoring signal x_{222}' will be at a high level
when pressure p_1 is less than or equal to the maximum
pressure value that occurs during operation of displacement
pump 1 within an undamaged flow vessel 13 communicating
with the liquid-sampling location in the manner described

15   above; otherwise, monitoring signal x_{222}' will be at a low
level.

In a further preferred embodiment of the first or second
variant of the invention, evaluation electronics 22, as

20   shown in Fig. 7, comprise a third Schmitt trigger 226,
which receives the measurement signal x_{223}. A filling
reference value of Schmitt trigger 226 is set so that a
binary third monitoring signal x_{223}' provided at its output
will be at a high level when flow vessel 13 is filled with

25   at least a predetermined minimum volume of the liquid to be
delivered; otherwise, particularly in case of increased air
bubbling in the fluid, the monitoring signal will be at a
low level. The filling reference value to be set may, for
instance, be determined by a suitable calibration

30   measurement and be set during start-up.

Monitoring signal x_{221}', monitoring signal x_{222}', and/or
monitoring signal x_{223}' are applied, if necessary through
analog-to-digital converters, to microcomputer 227 of
evaluation electronics 22. The status signal Z at the

5   output of microcomputer 227 can be delivered serially or in
parallel, for example to a display unit of the apparatus
serving to visualize the current operational status. The
status signal Z may also be applied to control electronics
for the displacement pump which, when a fault in the

10   apparatus is detected by measuring arrangement 2, for
example, turn the displacement pump 1 off. If necessary,
monitoring signal x_{221}', monitoring signal x_{222}', and/or
monitoring signal x_{223}' can also be derived from measurement
signal x_{221}, measurement signal x_{222}, and measurement signal

15   x_{223}, respectively, using trigger functions implemented in
microcomputer 227.

Preferably, microcomputer 227 is also used to implement a
triggered start function which serves to evaluate

20   monitoring signal x_{221}', monitoring signal x_{222}', and/or
monitoring signal x_{223}' only after turn-on of displacement
pump 1, namely after the lapse of a set interval of time
corresponding to a starting time.

25   The start function is triggered using a fourth monitoring
signal y_{14} of the apparatus, which signals a drive energy E
(see Fig. 3), particularly electric energy, that is fed
into displacement pump 1 during operation. Monitoring
signal y_{14} may, for instance, be a binary switching signal

30   whose high level signals that displacement pump 1 is on,
and whose low level signals that displacement pump 1 is
off. Monitoring signal y_{14} may also be a measurement signal

that represents, for example, a current being fed into
displacement pump 1. Furthermore, monitoring signal y_{14} may
also be derived from the aforementioned drive signal using
amplitude-measuring or rms-measuring AC-DC converters, for
5   example.

The interval of time for the start function is set so that
after turn-on, displacement pump 1 is definitely in the
steady state if there is no disturbance. The starting time
10   until attainment of steady-state operation must be
determined by calibration measurements and converted to the
interval of time to be set. Fig. 8 shows by way of example
a waveform of sensor signal x_{21} and a corresponding
waveform of measurement signal x_{221} during a transition to
15   steady-state operation.

In another preferred embodiment of the first variant of the
invention, microcomputer 227 incorporates a first logic
function which is activated by the start function and which
20   sets a first signal value for the status signal Z when
monitoring signal x_{222}' is at a high level and monitoring
signal x_{223}' is simultaneously at a low level.

In that case, the status signal Z may, for instance, signal
25   a clogged flow vessel 13.

In another preferred embodiment of the first variant and/or
the second variant of the invention, microcomputer 227
incorporates a second logic function, which is activated by
30   the start function and which sets a second signal value for
the status signal Z when monitoring signal x_{221}' is at a
high level and monitoring signal x_{222}' is simultaneously at

a low level. In that case, the status signal Z may, for
instance, signal "flow vessel 13 not immersed in the
liquid" and/or "leaky flow vessel 13, completely or partly
filled with air". This second signal value for status

5   signal S can also be generated, for example, by comparing
measurement signal x_{221} or measurement signal x_{222} with two
different signal reference values using two different
triggering levels, with the lower one of the two triggering
levels being exceeded by the measurement signal x_{221}, x_{222}

10 and the higher one being not reached.

In a preferred embodiment of the second variant of the
invention, in which sensor signal x_{21} signals the
deformation of support means 11 in the manner described

15 above, microcomputer 227 incorporates a third logic
function, which is activated by the start function and
which sets a third signal value for the status signal Z
when monitoring signal x_{221}' is at a low level and
monitoring signal y_{14} is simultaneously at a high level. In

20 that case, the status signal Z may, for instance, signal a
faulty pump drive 12.

It has turned out that even with pump drive 12 at rest,
support means 11, because of an initial tension exerted by

25 flow vessel 13 on its support, exhibits a small elastic
deformation which differs measurably from a basic shape of
support means 11 when pump drive 12 and/or flow vessel 13
are not installed, for example during maintenance work. By
fixing a corresponding lower limit value for sensor signal

30 x_{21}, it can be determined in evaluation electronics 22 by a
simple comparison with an instantaneous value of sensor

signal x_{21} whether pump drive 12 has been installed incorrectly.

In addition to pressure sensor 21' and/or strain sensor

5   21'', the measuring arrangement may comprise further sensors, such as temperature sensors used for temperature compensation, which may be mounted on flow vessel 13 or on support means 11, for example.

10   While the invention has been illustrated and described in detail in the drawings and forgoing description, such illustration and description is to be considered as exemplary not restrictive in character, it being understood that only exemplary embodiments have been shown and

15   described and that all changes and modifications that come within the spirit and scope of the invention as described herein are desired to protected.